
FOWT2018
Floating Offshore Wind Turbines
LEADING
COMMERCIAL
DEPLOYMENT
FOWT'S ACADEMIC SESSIONS
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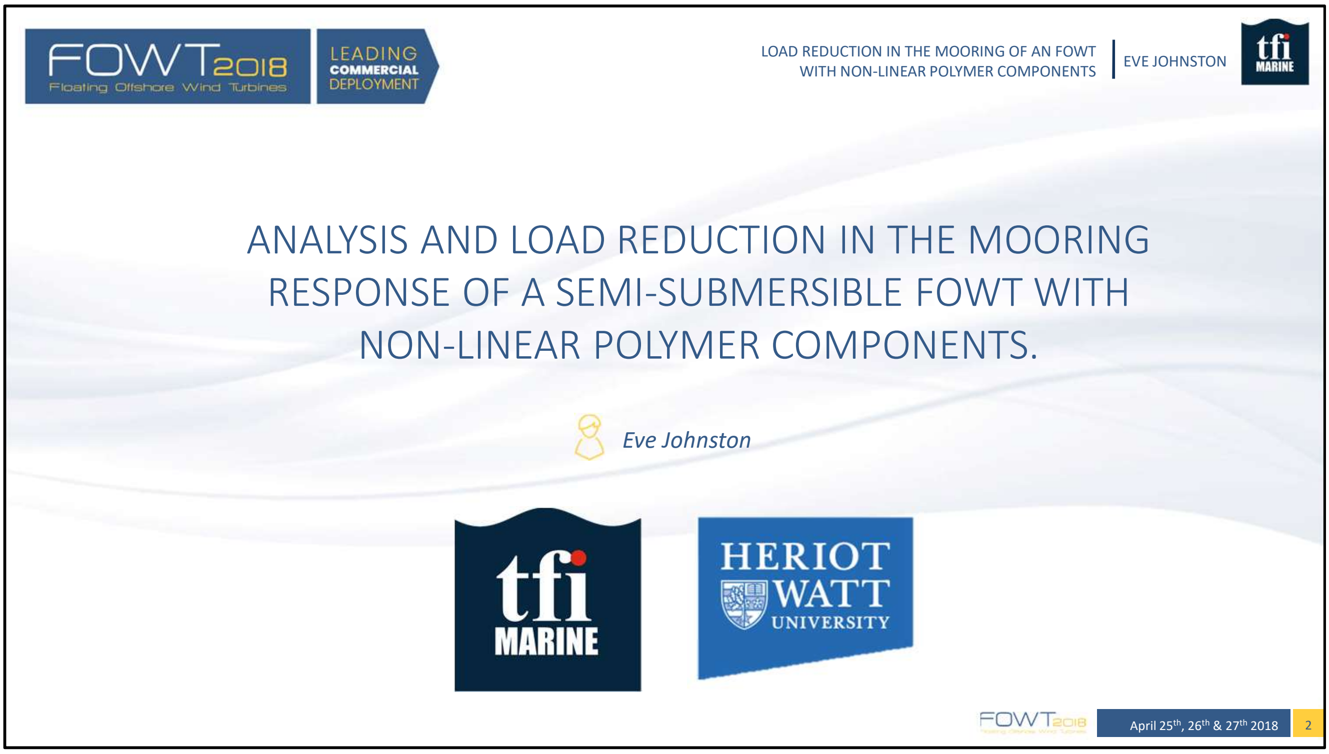
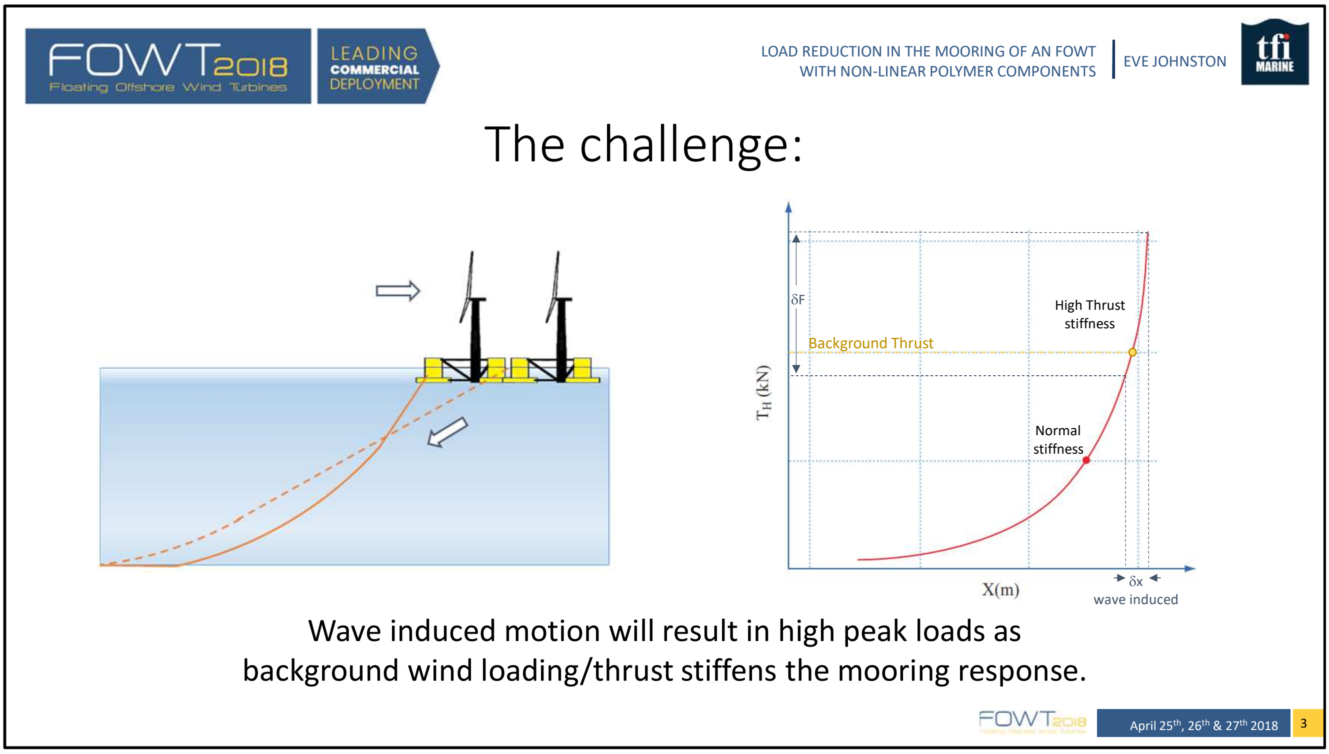
#FOWT2018

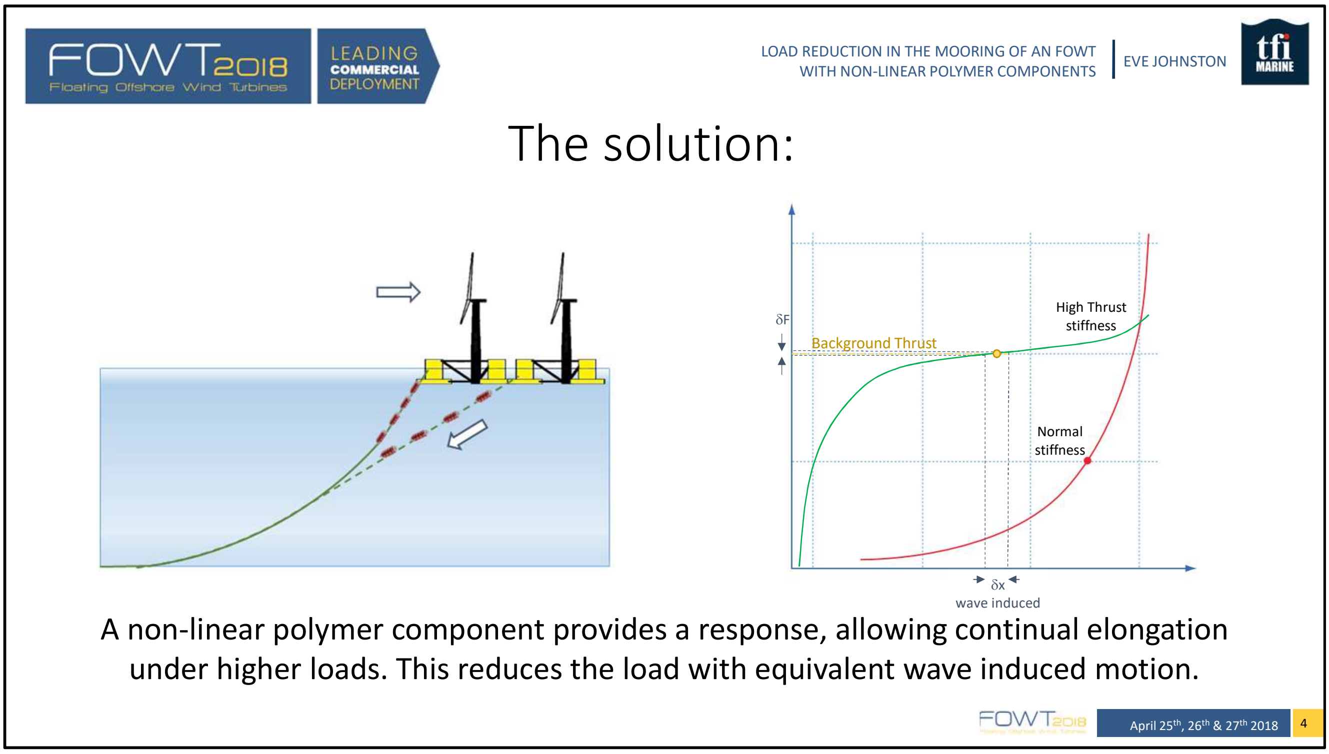


This research was conducted as part of masters undertaken by Eve Johnston at ICIT in Orkney in conjunction with TfI Marine in Dublin.

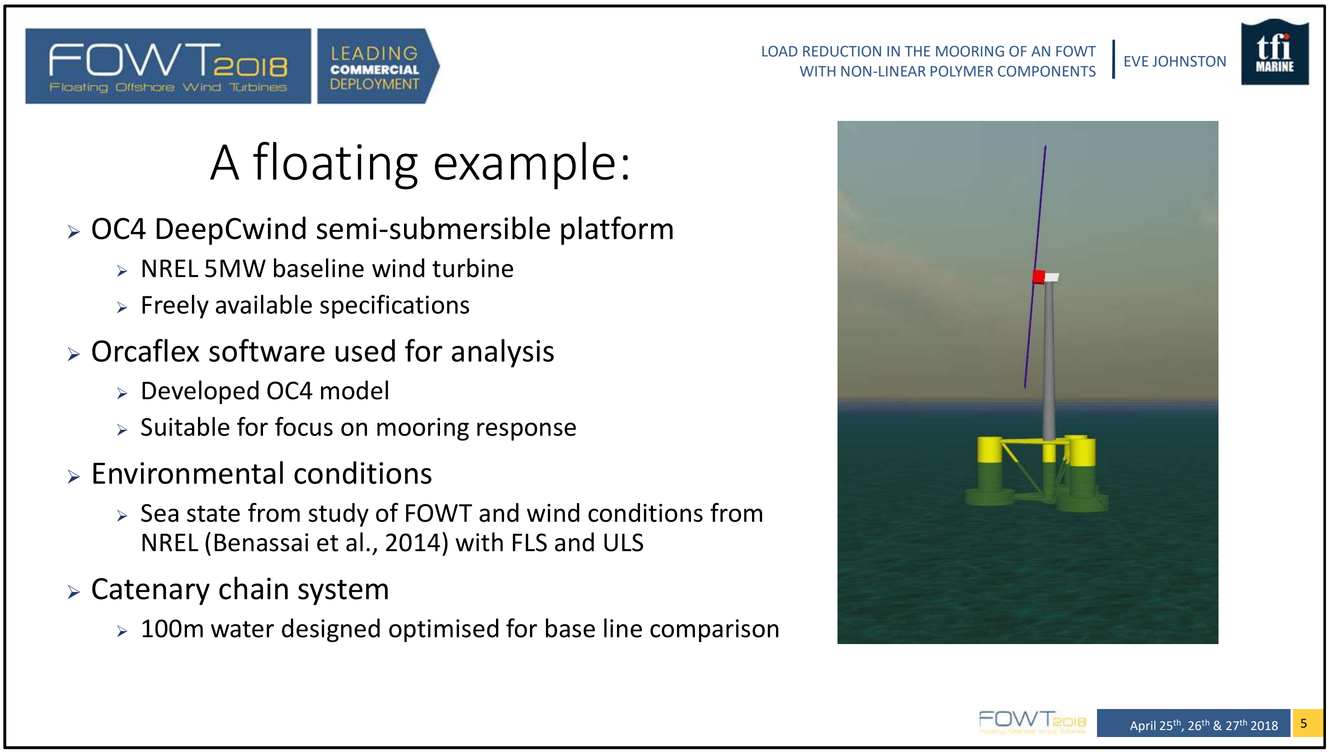
She would like to thank Heriot Watt, TfI Marine and all the FOWT developers who provided feedback and data for their support.



The graph on the left shows how the application of wind thrust to the turbines pushes the platform, lifting the mooring line. The impact of this on the mooring line stiffness is shown to the right, where the platform's position is plotted on the X axis and the tension of the line is plotted on the Y axis. As the platform moves to the right under wind thrust, the stiffness of the line increases. When wave induced motion is then applied, it results in large changes to the tension in the line, creating high peak loads and large cyclic loads.



The proposed solution investigated in this work is to insert the polymer mooring components into the mooring line enabling it to stretch and relax with the change in tension.
These components can have a substantially different response curve, as shown in the graph on the right. Under the same background load (caused by the wind thrust), the same wave induced motion now only causes a small change to the tension in the mooring line.

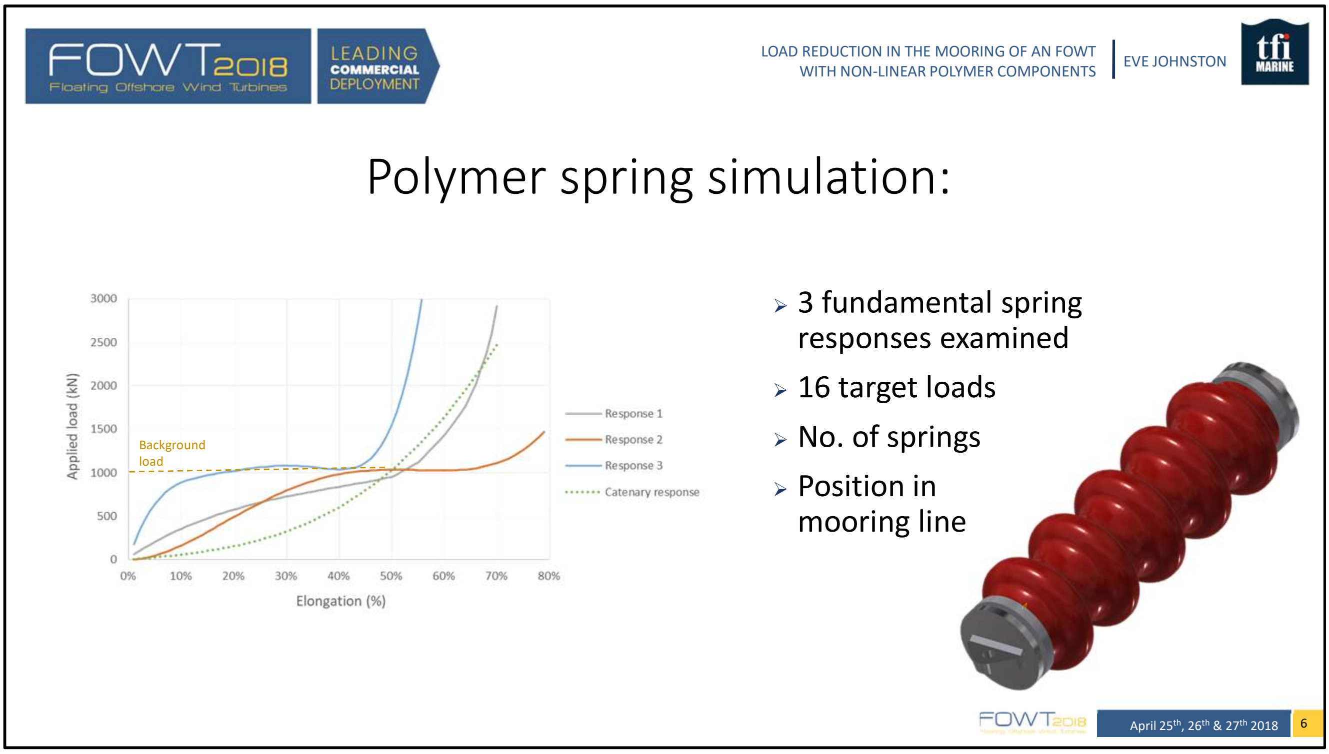


To investigate and optimise the behaviour of such components, an Orcaflex model of the OC4 DeepCwind semi-submersible platform was implemented. While some developers offered to allow for their FOWT to be modelled in this work, the publicly available data on the OC4 platform was used to ensure no confidentiality issues would arise in publishing the results. Orcaflex was chosen as it is widely used in the industry.

A catenary chain mooring system was implemented, designed for the 100m water depth in the highest load operating and survival cases. This was modelled with a variation of chain and length combinations to determine an optimal base case design based on both operational and survival conditions. Operational conditions assumed maximum wind power generation, while survival conditions assumed feathered blades and maximum environmental conditions. A wide range of sea states were analysed and the following two conditions chosen to represent the extreme load scenario for the two states;

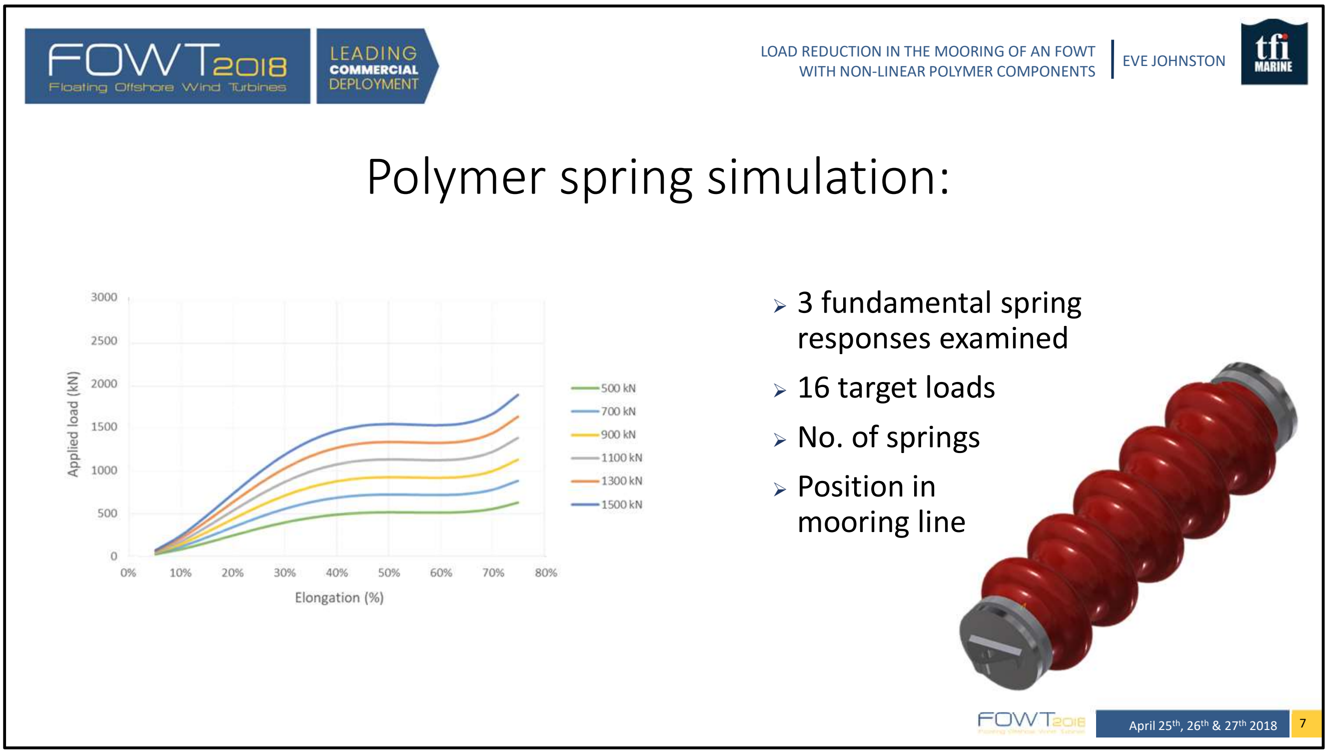
Operating Case (Fatigue Load State): Hs 8.6 - Tp 12.2 - Vw 11.4
Survival Case (Ultimate Limit State): Hs 12.5 – Tp 14 - Vw 52

Accidental Limit States were not considered in the scope of this work.

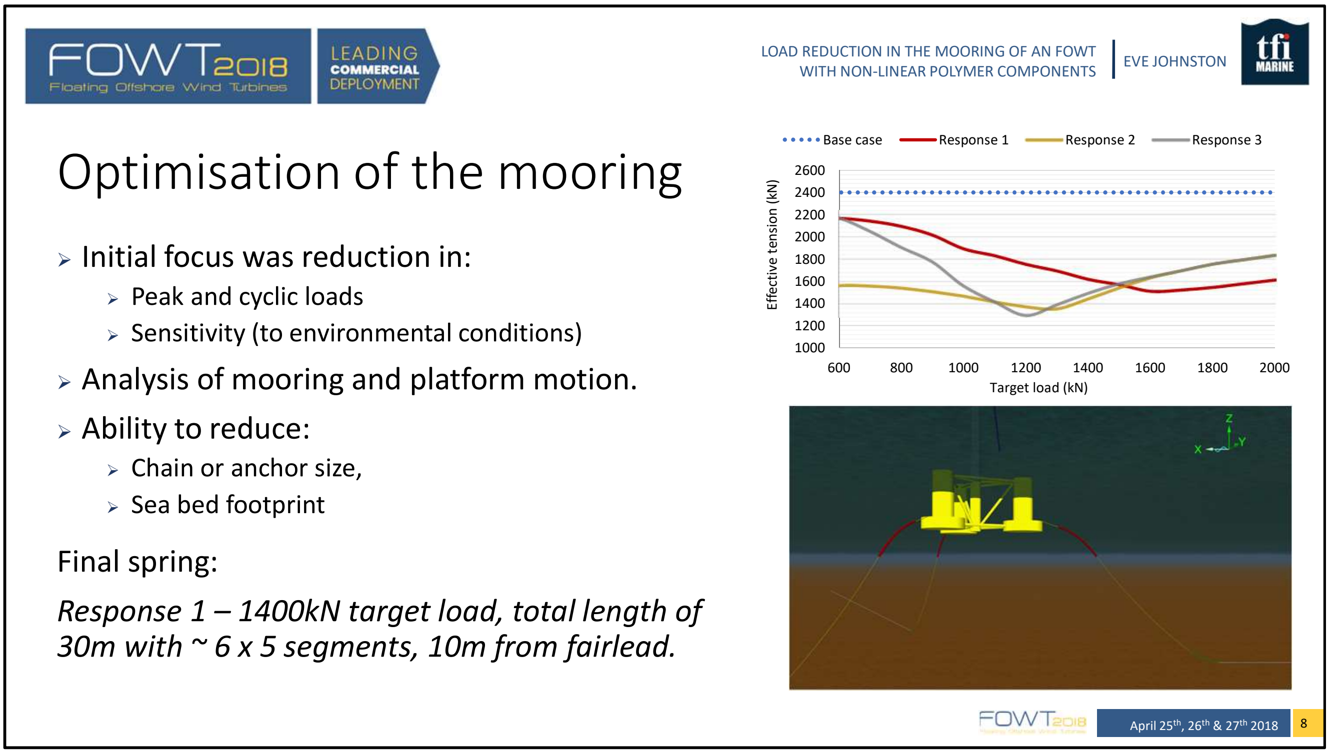


A key part of the dissertation work was the investigation of the impact of polymer component stress-strain response on behaviour. Three different fundamental spring response curves were therefore examined as shown in the graph. The response of a spring with a standard catenary response is also plotted as a comparison. For each fundamental response curve, a wide range of variables were considered.

Each curve was defined by a 'target load', which was the load on the component when it was elongated by 50%. This target load was varied, as were the number of polymer components (springs) in the mooring line (changing the overall elongation for a given applied load). The impact of the position of the springs in the mooring line was also investigated.



The graph above shows an example of the response curve as the target load is changed.

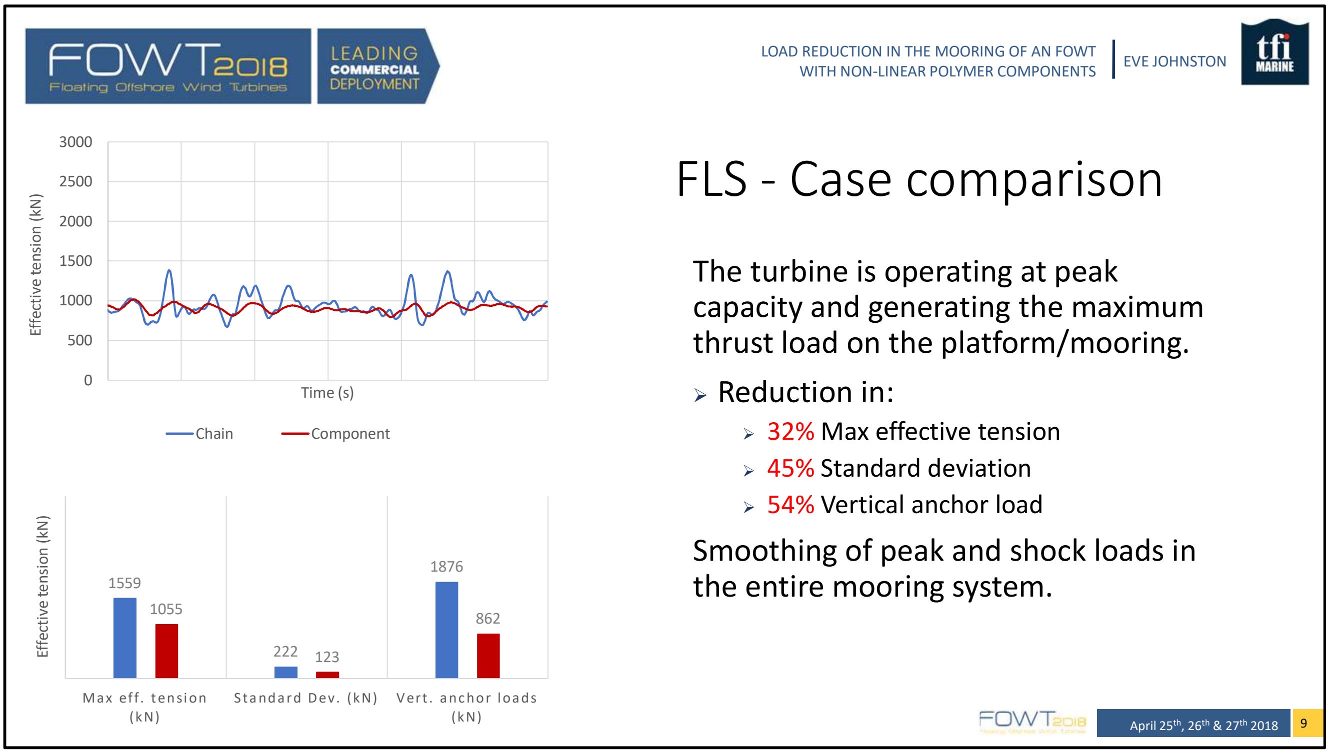


Each polymer component option is simulated for the both the FLS and ULS cases. Peak loads and cyclic loads are measured across all mooring lines. Platform motion (heave, surge, sway, roll, pitch, yaw) is also measured. Anchor loads and seabed contact points on the lines are also monitored.

To choose the most suitable component it is important that the variability in environmental conditions over time is considered. To consider this, sensitivity to input parameters was evaluated (environmental condition variations, manufacturing tolerances)

As the background wind load varies, the background stiffness of the mooring line changes. The graph on the top right plots the effective tension seen in the mooring line for three different polymer component response shapes, across a wide range of design target loads. While the lowest load is achieved by Response 3 at a 1200kN target load, this is not the most suitable component, as it is very sensitive to the target load. If the background wind changes much then the tension in the mooring line increases as the target load no longer matches the background load. Instead components with a broader response is desired, such as Response 2, here low tension is maintained even when the wind thrust drops.

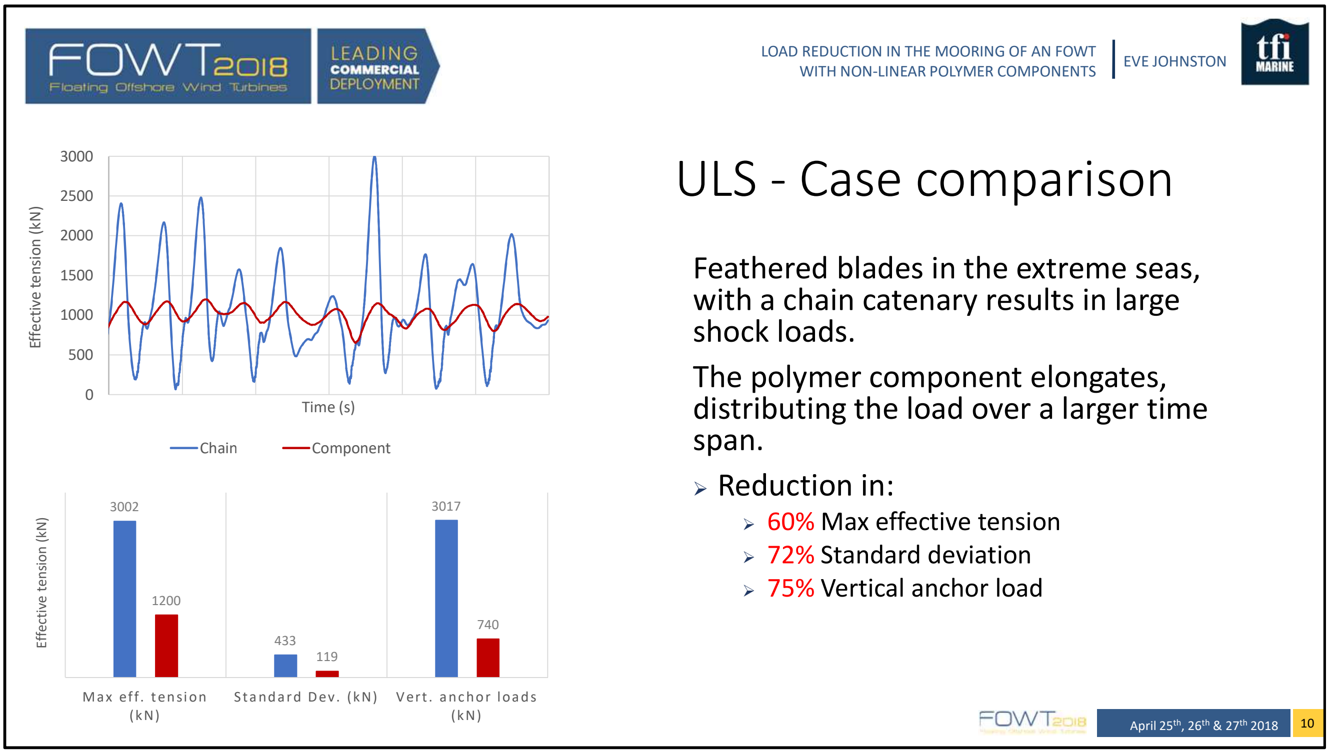
Sensitivity to the length of the component is also important though. The graph shows the response for mooring lines containing 4 x 5m long components. If 6 x 5m long components are instead used, then Response 1 delivers lower tensions across a much wider target load range. Optimisation will therefore also depend on the cost of the components and the incremental benefit of adding additional components into the mooring line. For the comparison data later, a 6 x 5m Response 1 component with a 1400kN target load has been chosen (installed near the top of the mooring lines), as shown in the illustration.



The graph to the top left compares the mooring line tension between the chain catenary base case and the polymer component case. Both peak loads and cyclic loads are substantially reduced, with no change to the mean load (caused by the wind thrust).

The graph to the bottom right compares the maximum tensions, the standard deviation in tension and the vertical loads on the anchor. The peak effective tension is reduced by 32% in this maximum operational case. The standard deviation is reduced even further, by ~45%. The variation in load (the cyclic load) is the cause of much of the fatigue in the mooring system, thus an important factor to consider for the lifespan and operational costs. While not explored in this work, further work which has been completed looking at detailed fatigue analysis of the mooring lines (using the rainflow method), and this shows substantial reductions in fatigue achieved by the use of the polymer components.

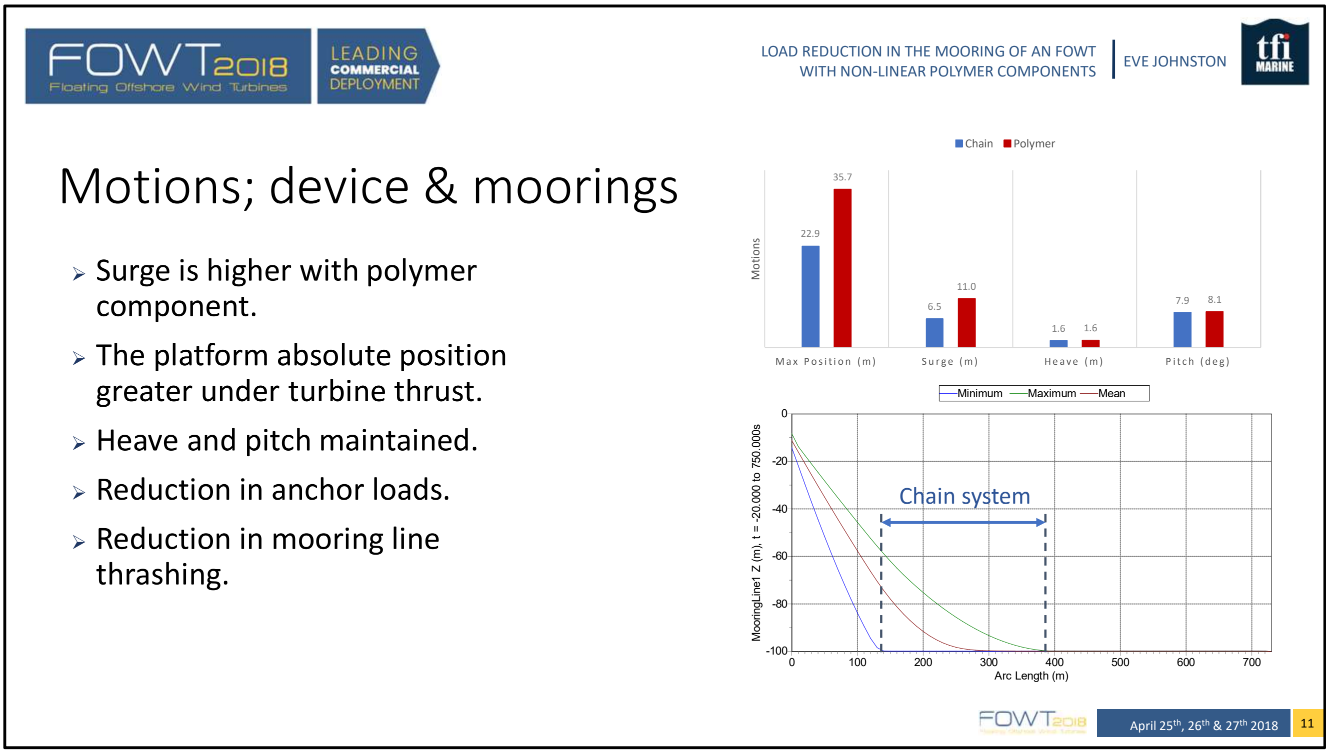
The vertical loads on the anchor are also compared and show >50% reduction using the polymer components. This would allow the designer to shorten the mooring lines and/or lighten the anchor/anchor chain.



On this slide the performance in the ULS scenario is compared between the chain catenary and polymer components cases.

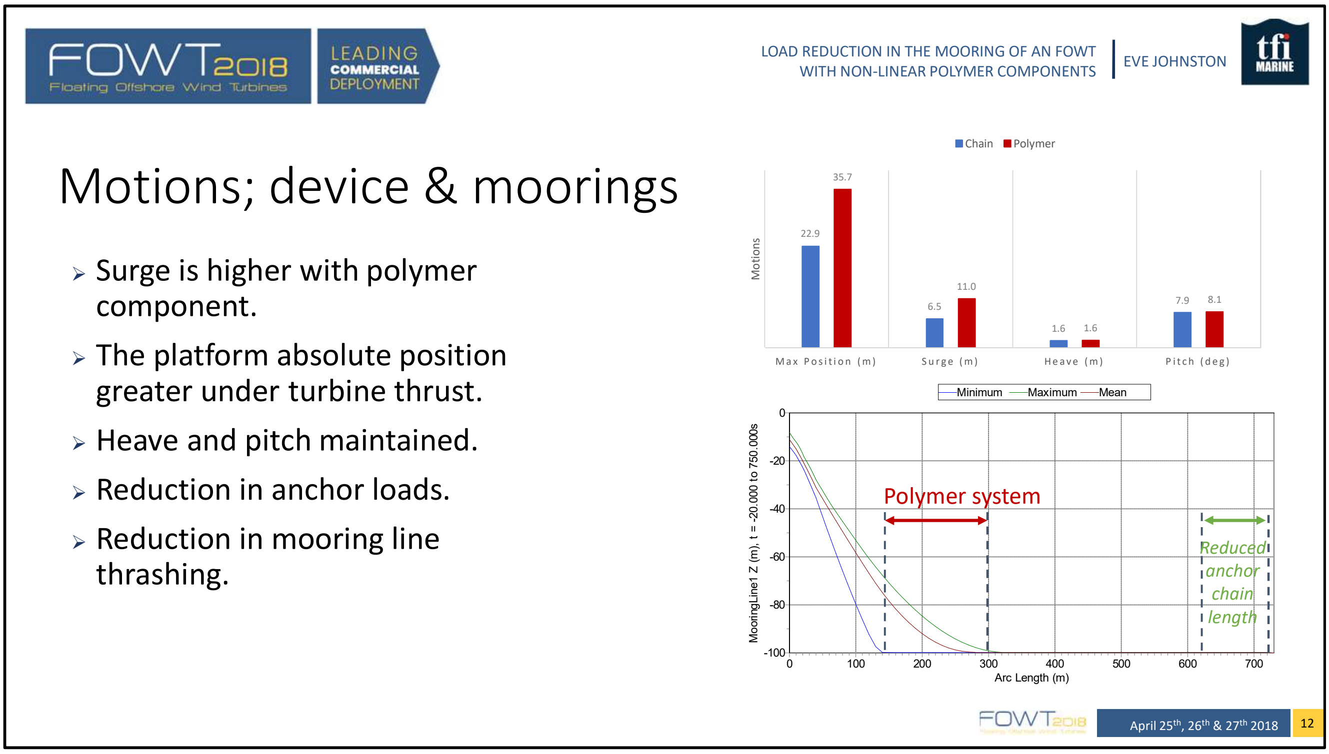
The graph to the top left compares the mooring line tension between the chain catenary base case and the polymer component case. Both peak loads and cyclic loads are again substantially reduced.

The graph to the bottom right compares the max tensions, the standard deviation in tension and the vertical loads on the anchor. The benefits of the polymer component are even larger in the survival sea states than the max operational sea states.



A key question to be investigated was whether the reduction in the loads came at the cost of some other performance issues. The top graph compares some of the device motion data, showing that while the surge of the platform is increased by the use of the polymer component, the heave and pitch remain the same. The platform therefore moves back and forward a bit more, but does so in a smooth manner with no change to the relative velocity at the turbine point, so no change to the power capture.

The bottom graph shows the position of the mooring line in the water column under max, min and average loads. In max loads (green line) the line is lifted almost 400m away from the device. In the lowest loads the chain is only lifted 140m away. This gives a span of 220m of chain length that lifts and falls (thrashes) on the seabed.



On this slide the bottom right shows the position of the polymer mooring line in the water during max, min and average loads. The span has been substantially, reduced, reducing the length of chain thrashing on the seabed by over 60m.

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LOAD REDUCTION IN THE MOORING OF AN FOWT WITH NON-LINEAR POLYMER COMPONENTS | EVE JOHNSTON

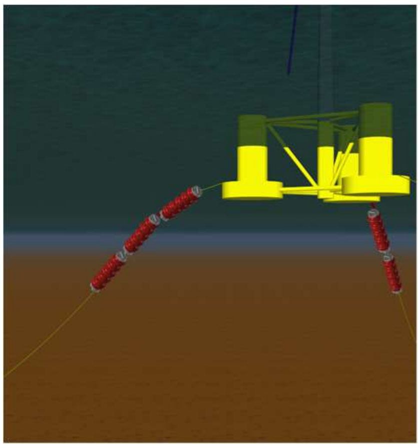
Conclusions

Study verified benefits of TfI polymer component in FOWT mooring system:

- Shock loads – 60% ↓
- Standard deviation – 80% ↓
- Suspended mooring lines – 25% ↓

The follow through benefits:

- Chain diameter, foot print, anchor size ↓
- Capital and operational expenditure ↓



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This research verified the capacity of significant load reduction in the mooring lines of FOWT with the polymer mooring components, and addresses engineering challenges experienced in the industry.

- Simulation and results validated the potential for the polymer spring to provide load reduction in the mooring system of an FOWT
- The benefits of the spring were most substantial in the reduction of sudden peak loads in the ultimate limit state cases under survival conditions, with up to 60% reduction
- The standard deviation and subsequent fatigue saw up to 80% reduction for the singular extreme case.
- While the lift off points of the anchor, thus the thrashing was 25% less than the original distance.
- With these substantial load and fatigue reduction cost benefits can be expected in both the capital and operating expenditure.
- Advantages include minimising the chain diameter, foot print, as well as the anchor and connection sizes. Further benefits could be seen in the lower loads experienced in the structure itself.

ANALYSIS AND LOAD REDUCTION IN THE MOORING RESPONSE OF A SEMI-SUBMERSIBLE FOWT WITH NON-LINEAR POLYMER COMPONENTS.

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Mooring Load Management

Questions ?
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